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PLATE XVI

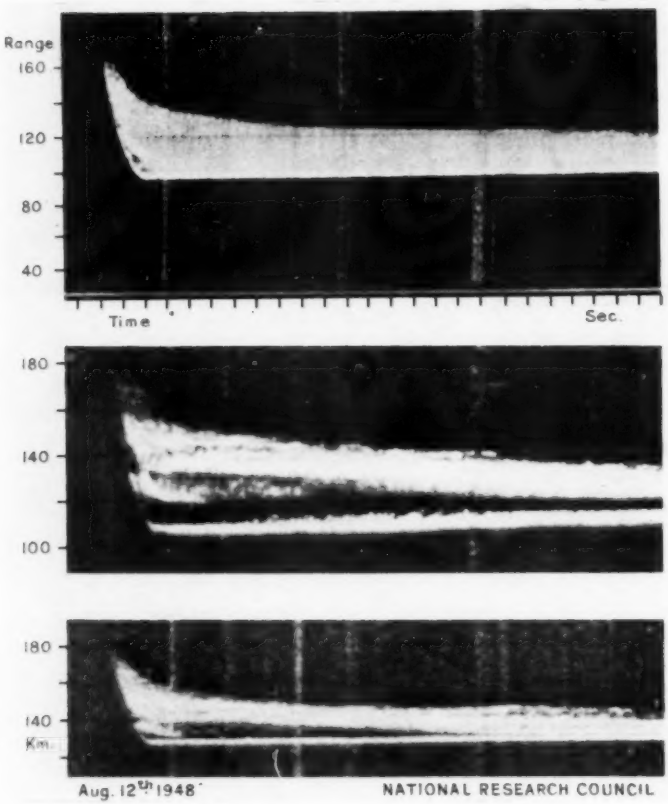

FIG. 6. Meteor Echo Photographed from Three Stations.

PLATE XV

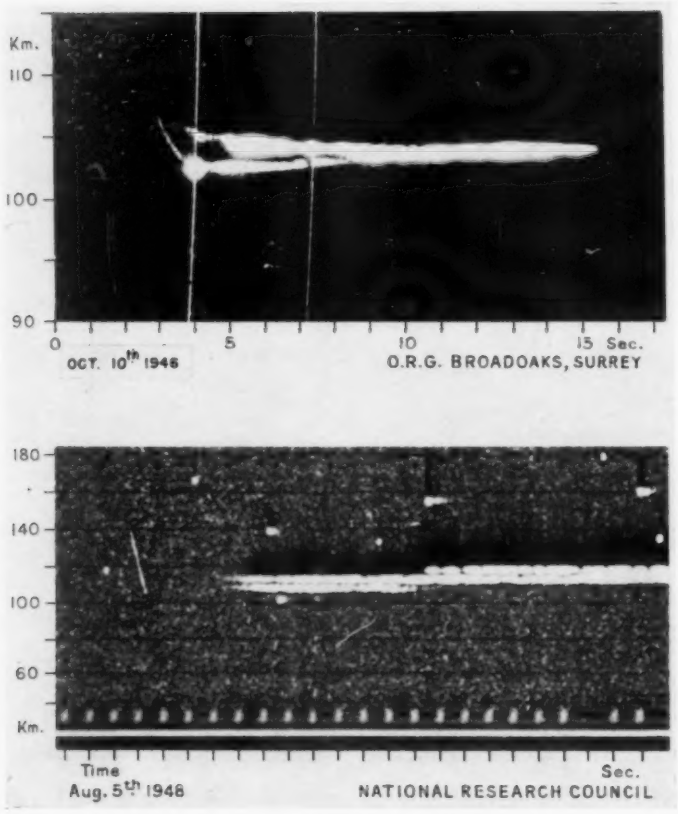

FIG. 5. Meteor Radar Echoes obtained with Equipment at 60 Megacycles Above and 30 Megacycles Below.

PLATE XIV

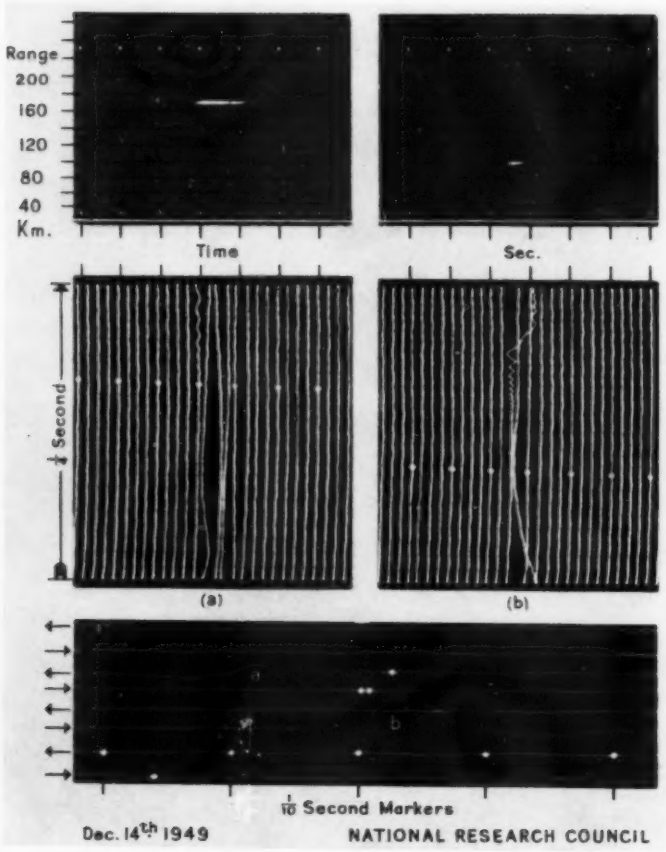

FIG. 4. Radar Echoes and Doppler Whistles of Two Meteors.
(a) Velocity 28 km./sec. (b) Velocity 47 km./sec.

PLATE XIII

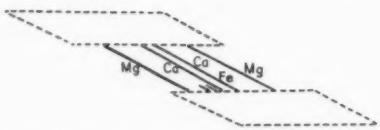

FIG. 3. Recombination Spectrum of Meteor Train.

PLATE XII

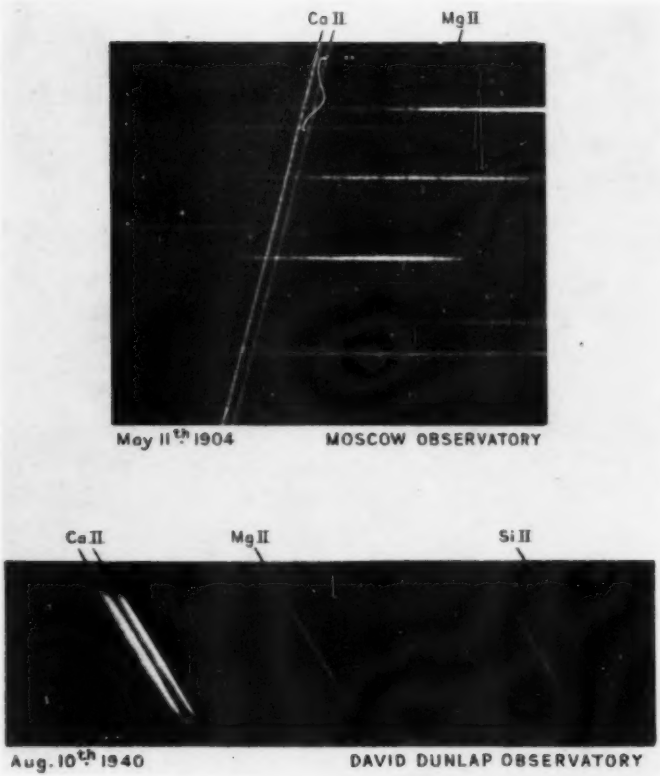

FIG. 1 Meteor Spectra showing Ionized Elements.

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METEORIC IONIZATION*

By PETER M. MILLMAN

(with Plates XII-XVI)

IN the case of the luminous phenomenon known as a meteor or shooting star we have a small solid object moving at very high velocity through a gaseous medium of density and pressure between one thousandth and one millionth that at sea level. To obtain a rough idea of the order of magnitude of the energies involved we may either list the total ergs corresponding to a representative range of meteor luminosities, Table I(a); or we may take the generally accepted range of meteoric masses and by combining these with known meteor velocities compute the respective kinetic energies, Table I(b). It is seen that typical meteor energies, for the class of object generally available to scientific study, range from 10^8 to 10^{15} ergs. It might logically be expected that with these energies dissipated in the upper atmosphere in less than a second, a certain amount of detectable ionization would result.

The first direct observational evidence of meteoric ionization was obtained when Blajko photographed a meteor spectrum at the Moscow Observatory on May 11, 1904,[1] and correctly identified the H and K lines due to the once-ionized atom of calcium. Although not identified at the time, Blajko's spectrum also showed a line of ionized magnesium, shown in figure 1, and since then lines of ionized calcium, magnesium and silicon[2] have been found to be normally

*Paper presented at the "Conference on Ionospheric Physics," Pennsylvania State College, Penn., U.S.A., July 24-27, 1950.

Contributions from the Dominion Observatory, Vol. 2, No. 8.

TABLE I

(*a*) ENERGIES CORRESPONDING TO METEOR LUMINOSITIES

Absolute Magnitude (stellar mag. at 100 km.)	Light Energy Radiated (in $\frac{1}{4}$ second)
− 4	2.1×10^{11} ergs
+ 1	2.1×10^{9}
+ 6	2.1×10^{7}
+11	2.1×10^{5}

(*b*) ENERGIES CORRESPONDING TO METEOR MASSES

Mass (gms.)	Total Kinetic Energy (ergs)		
	Velocity 20 km./sec.	40 km./sec.	60 km./sec.
100	2×10^{14}	8×10^{14}	18×10^{14}
1	2×10^{12}	8×10^{12}	18×10^{12}
.01	2×10^{10}	8×10^{10}	18×10^{10}
.0001	2×10^{8}	8×10^{8}	18×10^{8}

present in the light of all meteors with velocities greater than about 40 km./sec.

The "persistent train", a faint enduring luminosity observed in the wake of many bright meteors, is difficult to explain without the assumption of some ionization mechanism to store the energy which later appears as visible light. Olivier has catalogued[3] a vast quantity of heterogeneous observational material on meteor trains with durations from one minute to over an hour. This forms a very valuable source of reference material on the persistent trains of long duration. Olivier found for the trains appearing at night a mean height of 104 km. for the top of the train and 80 km. for the bottom. In 1935 Millman and Robins[4] summarized the persistent train observations associated with over 5000 meteors recorded in systematic visual observations of the annual meteor showers. The average train duration was computed for all meteors of a given magnitude. The brighter the meteor the longer was the mean train duration; the relation

between the logarithm of the mean train duration and mean magnitude being roughly a straight line. It was also noted that meteors of the faster moving annual showers had greater mean train durations, as shown in figure 2. It seems likely from recent photographic evidence[5] that the light of meteor trains results from a recombination of the ions formed by the dissipation of the original kinetic energy, as in figure 3. In addition to their contribution to the study of ionization, meteor trains also gave the first direct indication of high and frequently variable wind velocities in the ionosphere.[3,6,7,8] Mean velocities of 200 km. per hour were found by Olivier for the night trains.

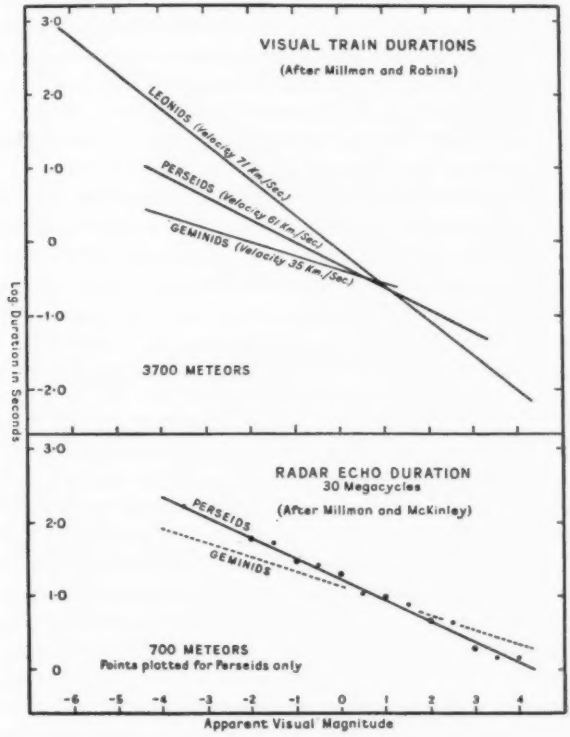

FIG. 2

Skellett was one of the first to suggest, in 1931,[9] that meteor ionization might possibly be detected by radio methods. Since that time evidence of the truth of this view, at first somewhat inconclusive, has steadily accumulated until to-day radio observations form one of the most important branches of meteor research. The greater part of the early radio work consisted of notes, chiefly qualitative, on the so-called "meteor whistles" frequently heard on the 1 to 100 megacycle band, and a search for changes in the basic parameters of the ionosphere during strong annual meteor showers. The great increases in the power and efficiency of radio equipment achieved during the war, added to the fortunate circumstance of an intense Giacobinid meteor shower on the night of Oct. 9, 1946, resulted in quantitative methods of radio meteor study which promise eventually to produce data rivaling in accuracy those obtained by any other means.

Radio observations of meteors, utilizing a radar (pulsed) technique, were first made in England,[10, 11, 12] Japan[13] and the United States,[14, 15] and later in Canada,[16] and a number of other countries. Frequencies from 3 to 200 megacycles per second have been employed and it has become evident that, within this range, the meteoric ionization may act as a detectable target whose reflection properties vary steadily with the frequency used. Features of meteoric ionization have also been studied by recording the rapid variations in the intensity of the reflected wave train (meteor whistles), either by using pulsed transmissions[17] or continuous wave transmissions.[18,19] A large amount of valuable information about meteors, both as astronomical bodies and as physical phenomena in the ionosphere, is being secured by the above techniques. It is with the latter phase of the subject that we are chiefly concerned here.

An attempt will be made to summarize briefly the general nature of meteoric ionization as indicated in the papers published by the radio research groups referred to above, supplemented by a considerable quantity of unpublished material secured by McKinley and Millman in the combined meteor observations being carried out at Ottawa. It has been reliably established, both on theoretical grounds and by photographic observations,[20, 21, 22] that the dissipation of the major part of the kinetic energy of the meteor in the atmosphere coincides with a steady loss of meteor mass, rather than with any marked decrease in meteor velocity. The appearance of visible light, and the production of ionization (as distinct from its endurance or

detection), also coincides with this loss of mass. Since all meteors normally observed originate as small solid particles moving along a straight line, the basic ionization will be produced directly along this line and will immediately commence to diffuse at a rate of radial expansion which, up to the present, has not been determined very exactly. This diffusion rate may safely be estimated to lie in the range 1 to 100 metres per second. Combining this with known meteor velocities we have a very narrow cone of ionization, the half angle at the vertex being a small fraction of a degree. This ionization cone soon loses its regular outline and rapidly becomes deformed by diffusion and turbulence in the upper atmosphere. There is evidence that additional secondary ionization, much more attenuated than the basic ionization cone, is produced around the meteor itself by some mechanism, possibly involving strong ultra-violet radiation.[16]

The terms "basic ionization" and "secondary ionization" will be used to differentiate these two types in the following discussion. How and when will this ionization be detected by radio equipment? Let us assume, for the moment, equipments with a standard figure-of-merit, and meteors of a standard velocity and brightness. Whether, at any given instant, a signal will be received or not will then depend chiefly on four parameters:

(a) the frequency used, ν.

(b) the angle between line of sight and the meteor path, α.

(c) the time since the passage of the meteor.

(d) the height of the meteor, H.

The cone of basic ionization, immediately after the meteor has passed, approximates a narrow line of electrons and, as Lovell has shown, can be treated like an infinitely long line of scattering sources. This will return a radio signal and Lovell's scattering formula requires that the echo power vary as the reciprocal of ν^3. This has been checked experimentally.[24] The duration of these echoes is generally measured in fractions of a second since the basic ionization approximates a straight line for only a short time. The number of echoes recorded increases by the predicted amount as the frequency used is lowered. This type of target gives a signal which is received in strength only perpendicular to the meteor's path; in other words only meteors with α near 90 degrees will be observed in this way. If this echo is produced by a reflection mechanism rather than one

of scattering, observations on different frequencies should show a different arrival time for the echo, as McNish has pointed out.[25] Up to the present, observational evidence supports the scattering theory.

This "linear" ionization can be recorded by both the pulsed and the continuous wave techniques, as illustrated by some of McKinley's photographs reproduced in figure 4. McKinley has shown[19] that the form of these Doppler whistle curves can be explained by using diffraction theory and by integrating the contributions of all the elements along the meteor path up to any given instant of time. Applying this theory the velocity of the meteor can be determined from measures of the variation in beat frequency as the meteor approaches and recedes from the point where $a = 90°$, assuming the range at this point is known from the radar record. The formula used to determine velocity is very similar to the one derived from the simplified assumption that the wave is reflected from the moving meteor head.

On the basis of Öpik's theoretical work[20] Herlofson has estimated[26] the order of magnitude of the number of electrons produced in the basic ionization cone and concludes that the kinetic energy of the meteor is distributed into heat, light and ionization energy roughly as the ratios $10^4 : 10^2 : 1$ respectively. Assuming a mean velocity of 40 km./sec. this gives 10^{10} electrons per cm. of path for a sixth magnitude meteor and 10^{12} electrons per cm. of path for one of first magnitude. Lovell and his co-workers have shown[24, 27] that these values of electron densities are of the same order of magnitude as those determined observationally, using Lovell's scattering formula. McKinley has shown in a paper not yet published[28] that even less than 10^{-4} of the total meteor energy may account for this type of ionization observed in the case of two meteors whose decelerations have been studied in detail at Ottawa.

We may summarize briefly then by noting that a reasonable theory has been proposed to explain the radio signals received from the narrow line of basic ionization remaining immediately after the meteor has appeared. The observational values agree with the theory as well as can be expected. The basic ionization cone does not remain in the form of a narrow line, however, but rapidly expands and diffuses. The radio signals received during this second phase of the basic ionization cannot be quite so easily explained on theoretical grounds. As Lovell[29] and others have pointed out this is one of the chief problems in this field requiring solution.

Figure 5 (a), a Giacobinid echo secured by Hey, Parsons and Stewart[20] illustrates a typical strong enduring radar echo received from the second phase of the basic ionization using 60 megacycle equipment. Figure 5 (b) shows the beginning of the same type of echo photographed at Ottawa on 30 megacycles. These echoes are returned by the diffusing cone of basic ionization and may have durations of several minutes. Means of the log. durations in seconds for 7000 Perseid and Geminid echoes observed at Ottawa, 1947-1949, are plotted in figure 2 against visual magnitudes. The similarity to the corresponding curves for the visual meteor trains is striking and it is likely that we are dealing here with two evidences of the same phenomenon.

These enduring echoes appear over a wide range of a's, and they can be detected over a fair range of frequency, though they are far less numerous and of shorter duration on the higher frequencies. The majority of the echoes in this group appear at one or more discrete ranges ('F' and 'E' types on the classification of McKinley and Millman);[16] but frequently, for the early part of its life, the echo is continuous over a spread of ranges ('b' characteristic). A good example of this type, photographed simultaneously from three stations near Ottawa, is shown in figure 6.* Studies of the 'b' contours indicate that this echo duration varies in a regular manner with the height.

The difficulty in the case of these enduring echoes arising from the basic ionization is to explain why they last so long. For example, from figure 2, the average duration of a zero magnitude Perseid echo is found to be 15 sec. According to Herlofson's theory such a meteor would produce somewhat under 10^{13} electrons per cm. of path. But, even if we disregard recombination and assume a diffusion rate of only 5 m./sec., this electron cloud would diffuse to the critical electron density (10^7 electrons/c.c. at 30 megacycles) in approximately 1 second. Since at least some recombination must take place it is clear that, to explain a duration of 15 seconds requires between 10^2 and 10^3 as many electrons as given by Herlofson's theory. That radial diffusion exists, at least of the order of magnitude assumed, is indicated both by the observation of diffusion rates in visual meteor trains, and by the necessity of having an electron cloud of a certain minimum size to reflect 10-metre waves in all

*Preliminary measures of this day-time Perseid meteor by McKinley give echo heights from 126 km. to 87 km. and a velocity of 60 km./sec.

directions. The problem may be examined in another way. Assume, conservatively, that the lines of ionized calcium contribute 1/10 of the light of this zero magnitude Perseid. Using the radiant energies given in Table I we find that 3×10^{13} calcium atoms per cm. of meteor path must be contributing to the production of the meteor's light. Since each ionized calcium atom must have lost an electron, the calcium atoms alone produce more electrons per cm. of path than the total number assumed by Herlofson.

Before discussing this further, reference should be made to the evidence for secondary meteoric ionization. This produces a moving echo ('h' characteristic) with a duration too short to be estimated using present techniques. It was first observed by Hey, Parsons and Stewart[30] in 1946, and is shown in figure 5. This echo appears with or without the 'b', 'e', and 'f' characteristics and, where the resolution is good, may be clearly separated from them, as in figures 5 and 6. It is observed over a wide range of α's and even for meteors coming practically head-on.[31] This echo apparently moves with the velocity of the meteor and is presumed to originate in a diffuse cloud of electrons which McKinley and Millman have tentatively suggested[16] might be produced by intense ultra-violet light from the meteor head. In this case the ionizing agent will act almost simultaneously throughout a sphere centred on the meteor and must produce an ion density which, for a very short time, is greater than the critical density for the frequency used. Rapid recombination will prevent any effective duration of this echo. It must be admitted, however, that there are serious difficulties with this explanation, particularly from the standpoint of the efficiency of the mechanism.

We are now faced with the problem of the difference in the behaviour of the basic ionization and the secondary ionization. The former frequently remains for an abnormally long period after it has been formed while the latter disappears rapidly. Although our knowledge of the physical constants governing the duration of meteoric ionization is still very incomplete. the behaviour of the secondary ionization would seem to be more what one would expect than that of the basic ionization. No satisfactory explanation for this problem can be offered at the present time but, in any attempt to reach a solution, it will be of value to note the difference in the physical conditions accompanying the two types of ionization. The secondary ionization will be formed in an atmosphere of oxygen and nitrogen

and the electrons will be derived chiefly from the atoms and molecules of these elements, with ionization potentials in the neighbourhood of 14 — 15 volts. In addition to normal recombination the numbers of electrons will be further reduced by the tendency of oxygen to form negative ions by the capture of an electron. The basic ionization, on the other hand, will be formed in an atmosphere containing an appreciable percentage of meteor atoms, e.g., iron, calcium, magnesium, silicon, etc. These have low ionization potentials, 6 — 8 volts. What is probably more important, however, is that, assuming the number of electrons determined observationally by using the scattering formula, the basic ionization appears in a volume filled with heat energy at least 10^4 times as great as the energy of ionization. Since collision excitation must be assumed as one of the major factors producing the basic ionization, this large quantity of heat energy in the form of molecular velocities may have some effect in maintaining the density of electrons in the basic ionization cone. In contrast, the meteor luminosity drops by a factor of the order of 10 or more in 1/400 of a second, as has been shown by Millman and Hoffleit[32] from rotating shutter photographs. Hence the factor which may produce secondary ionization has only a very brief duration.

Conditions in the ionosphere must play an important role in the maintenance of the enduring basic ionization echoes. Evidence of this is found in the Ottawa data where, even for meteors with α's differing from 90 degrees, and which therefore produce a linear column of basic ionization over a fair spread in range, an echo of significant duration is found at only one range for a large percentage of cases. The possibility of small areas in the ionosphere particularly favourable to enduring ionization has already been pointed out by McKinley and Millman.[16] These same authors have in preparation a paper dealing in part with certain exceptional long duration meteor echoes which appeared on the night of Aug. 4-5, 1948. The ionospheric conditions at this particular time must have been very favourable to abnormal durations.

Apparently the meteoric ionization that can be detected by radio methods does not exhibit as great a range in height as is found for the visible meteor luminosity. The great majority of meteor echoes studied at Ottawa lie in the height-range 80 to 120 km. and this can conveniently be called the M-region. Methods of height deter-

mination, using three radar stations and one or more visual stations have been described by Millman and McKinley,[33] and typical heights determined for Aug. 10-11, 1948 were given in this paper. The reduction of some 2500 meteors, observed 1947-1949 in the combined Dominion Observatory - National Research Council programme at Ottawa, and recorded by both visual and radio methods, is now near-

TABLE II

PRELIMINARY MEAN HEIGHTS OF RADAR ECHOES

Three-station Radar Heights (all meteors identified visually)

		Perseids '48 '49 H	Non-Perseids '48 '49 H
'e' & 'f' echoes:	dur. $\geqslant$ 3 sec. all sta.	97 km. (94)	92 km. (43)
	dur. $<$ 3 sec. one sta.	107 (23)	100 (5)
'h' echoes:	beginning	113 km. (16)	
	end	100	
'b' echoes:	beginning	113 km. (14)	
	end	101	

One-station Heights Computed from Radar and Visual Observations

			H
All echo types:	Perseids	'47	102 km. (96)
		'48	102.9 (110)
		'49	102.8 (223)
	Perseids	'47 '48 '49	102.6 km. (429)
	Non-Perseids	'47 '48 '49	97.1 km. (157)
All echo types:	Geminids	'47	96.9 km. (138)
		'48	98.3 (53)
		'49	96.4 (111)
	Geminids	'47 '48 '49	97.0 km. (302)
	Non-Geminids	'47 '48 '49	98.5 (112)

Numbers of meteors averaged are given in brackets.

ing completion. Some of the preliminary values of mean heights determined from these reductions are listed in Table II. There is no significant difference in the mean heights found for the same shower in successive years. It will be noted that the Perseid echoes are 5 or 6 km. higher on the average than the Geminid echoes. This difference is probably real and agrees in general with visual and photographic height determinations, though the change in mean height with velocity is smaller for the radar echoes. The possibility of a seasonal effect, similar to that described by Whipple, Jacchia and Kopal,[34] must not be neglected. A more reliable value of variation of radar echo height with meteor velocity and with the time of year will be available when more of the three-station radar results have been reduced. The mean apparent magnitudes for the meteors in Table II lie between +1 and +2. The heights listed here agree in general with those determined by other methods.[35]

As mentioned above, visual meteor train observations have given evidence of high wind velocities in the upper atmosphere. Both the one-station and three-station radar observations indicate a slow change in the range of the echo over durations lasting of the order of minutes. Undoubtedly some of this effect results from a general drift of the ionization cloud of a type similar to that observed in the case of the visual trains, but certain complicating factors are present which make the radar drifts difficult of complete interpretation. The matter has not yet been investigated in detail for the Ottawa records. Manning, Villard and Peterson[36] have recently devised a technique for the study of upper atmospheric winds using the frequency shift in their Doppler records. Preliminary tests of the method appear promising and further observational results from Stanford will be awaited with interest.

A more detailed quantitative study of several phases of the meteoric ionization problem is now in progress at Ottawa, based on the accumulated observational results obtained to date.

In conclusion I should like to thank Mr. J. S. Hey for making available a copy of the radar echo from Broadoaks in figure 5. I should also like to thank Dr. D. W. R. McKinley for supplying the National Research Council photographs accompanying this paper and for much helpful discussion concerning the text.

Dominion Observatory, Ottawa

July 19, 1950

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[35]Clegg, J. A. and Davidson, I. A., *Phil. Mag.*, ser. 7, vol. 41, p. 77, 1950.

[36]Manning, L. A., Villard, O. G. and Peterson, A. M., *Proc. I.R.E.*, vol. 38, p. 877, 1950.

PLATE XIX

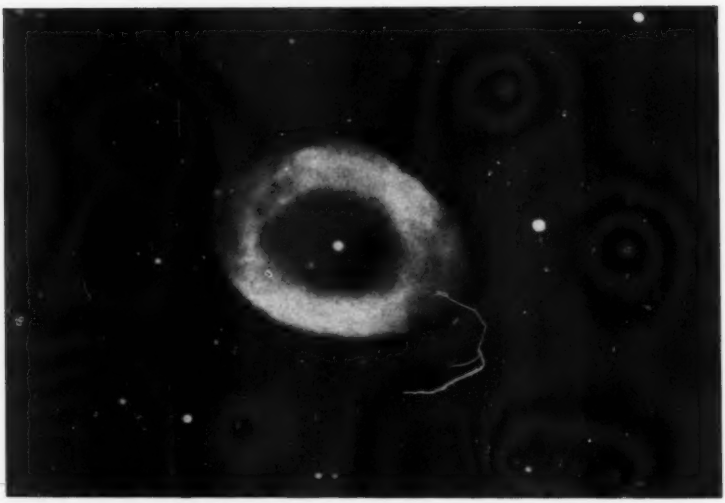

Fig. 5. The Ring Nebula in *Lyra*, photographed with the 73-inch Victoria Telescope. This ring-like object is composed of a number of shells of gas, of exceedingly low density, surrounding a very high-temperature star. The gaseous shell shown is made luminous by the absorption of energy radiated by the central star. The shell seen in this photograph is so vast that it would take light nearly a year to cross it.

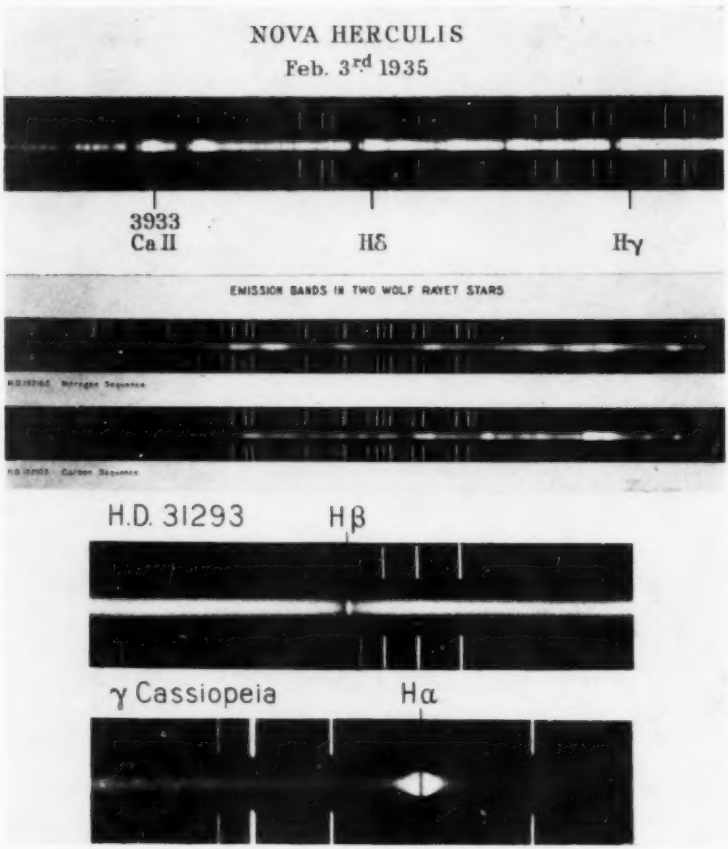

Fig. 2. Displaced Absorption Lines and Emission Bands in the Spectrum of Nova Herculis. The broad emission bands with absorption borders on their violet edges are believed to be due to the ejection of material from the stellar surface. This spectrum represents a relatively early stage in the nova outburst when the temperature is still comparatively low.

Fig. 3. Spectra of Two Wolf and Rayet Stars. The Wolf Rayet Stars (discovered by Messrs. Wolf and Rayet at the Paris Observatory in 1867) are remarkable for the bright emission bands which appear in their spectra. Studies of these stars made at Victoria have indicated that the bright bands are due to an envelope of gases surrounding the star. This envelope is caused by the ejection of gases from the star by radiation pressure with velocities sometimes as great as 4000 kilometres per second. These envelopes are not uniform in chemical composition, some showing an excess of carbon and oxygen, while others show mainly nitrogen. Temperatures determined by Zanstra's method for these stars indicate values ranging from 50,000° to 100,000°.

Fig. 6. Emission Lines in Be Stars. These spectra show two of the characteristic features of emission lines of this type e.g. the appearance of an emission line superimposed on broad absorption (H.D. 31293) and a relatively broad emission line cut by sharp absorption, (γ Cassiopeiae).

PLATE XVII

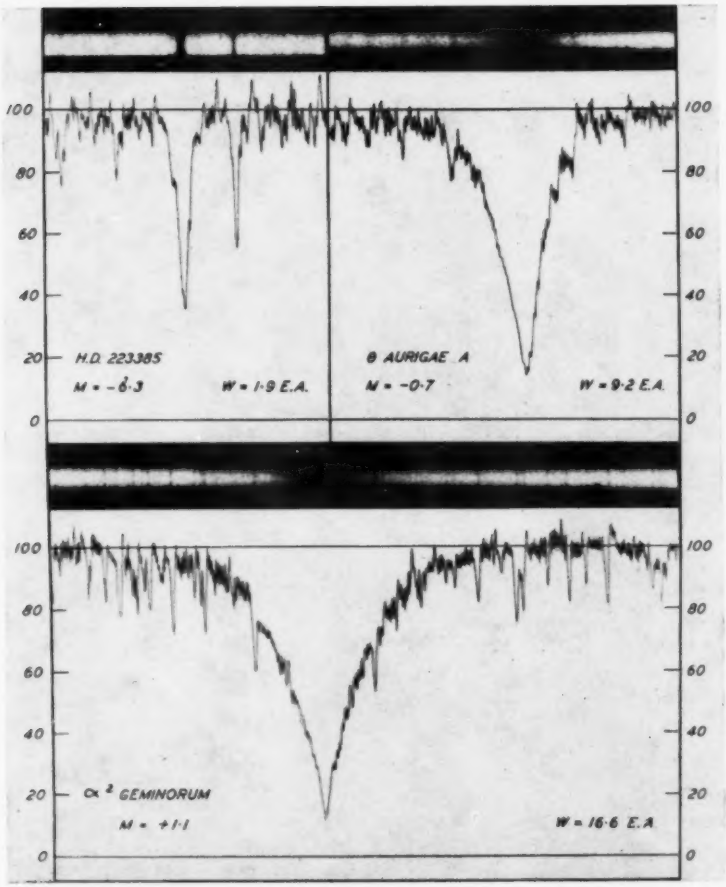

Fig. 1. The Influence of Stark Effect on the Hydrogen Line Profiles of A-Type Stars. Here are shown three line profiles of $H\gamma$ in stars of differing absolute magnitude. It will be seen that the most luminous star, H. D. 223385, has a relatively narrow $H\gamma$ line, while the star α^2 Geminorum, which is 7.4 magnitudes fainter, has a line of great breadth. θ Aurigae is intermediate between the two. Worth quoting are the narrow metallic lines which accompany the broad hydrogen absorption in α^2 Geminorum. Courtesy Dr. R. M. Petrie.

THE ATMOSPHERES OF THE EARLY TYPE STARS*

By C. S. Beals

(with Plates XVII-XIX)

Abstract

Reference is first made to general studies of stellar structure and to the fact that stars are completely gaseous bodies with no sharp division between atmosphere and interior. The term atmosphere is restricted to the layers susceptible to direct observation.

The influence of Stark effect due to near approaches of ions and absorbing atoms in broadening and otherwise distorting the lines of hydrogen and helium is discussed and it is pointed out that the tremendously wide wings of hydrogen lines in A-type stars are largely due to this cause. The Stark effect of hellium is less marked but a number of observations of line profiles and intensities indicate its presence in certain stars of class B.

Three types of motion are known to influence the profiles of lines in early type stars. These include rotation of the star as a whole and turbulence in the atmosphere. Both of these effects act to broaden and flatten the stellar lines making it difficult to study the stellar atmosphere in the detail that would otherwise be possible. A third important type of motion in early type stars is the ejection of gaseous material into space with velocities which may range from a few tens to a few thousands of kilometres per second. An important consequence of such motions is the formation of gaseous envelopes around the stars, in which emission lines may have their origin. A few early type stars show atmospheric pulsations of the type usually associated with Cepheid variables, but this is not in general a feature of the hotter stars.

The temperatures derived for absorption line stars depend upon the application of Planck's law to the observed distribution of energy in the continuous spectrum and on the use of Boltzmann's and Saha's formulas for the distribution of atoms in excited or ionized states. It is shown that for the hotter stars, the latter methods are more reliable and values are given for early type absorption line stars which range from 13,000° for A0 to 36,000° for O5.

On the assumption that emission lines in early type stars are due to Zanstra's mechanism of ionization and recombination, temperatures may be derived for all classes of stars which show emission lines from the early A's to the nuclei of the hotter planetaries. These results, combined with values for the absorption line stars lead to the following temperature scale for the early type stars: A0, 13,000°, B0, 20,000°, O5, 40,000°, W5, 100,000°, hotter planetary nuclei 140,000°. The place of the W stars and the hotter planetaries in the stellar sequence is discussed and the possibility is suggested that their spectral peculiarities may be a consequence of surface temperature alone and that they, therefore, represent simply an extension to higher temperatures of the classification sequence as now accepted.

Presidential address delivered before Section III of the Royal Society of Canada, Royal Military College, Kingston, June 6, 1950. Part of a Symposium on "The Atmospheres of the Stars and the Planets".

Introduction

Those of us who were responsible for planning this symposium almost a year ago probably did not realize fully at the time what a large part of astrophysics our subject took in. A glance over some of the major publications devoted to the physics of the stars during the past two decades reveals the fact that well over half the titles real either directly or indirectly with the atmospheres of the stars and the planets. Under such circumstances, it is scarcely necessary to say that we cannot undertake anything like a complete summary of this field. The papers presented will rather stress a few major developments in this part of astrophysics and where possible endeavour to link them with interesting aspects of terrestrial physics. Insofar as my own contribution is concerned it has served to emphasize again something that scarcely needs emphasis, namely that physics and astrophysics are one subject and that there is no dividing line between them.

While this paper deals with the atmospheres of the early type stars, it is scarcely possible to discuss stellar atmospheres without making at least some reference to the structure of a star as a whole. It is very pleasant, in fact, to have an occasion to refer to some of the results which have been achieved in the study of stellar interiors since this is one of the brightest chapters in the whole history of modern science. While the interior of a star is not susceptible to direct observation, the application of the methods of mathematical physics to gas spheres of appropriate mass and chemical composition by Lane,[1] Emden,[2] Eddington,[3] Jeans,[4] Chandrasekhar[5] and a host of others has led to a reasonably logical and consistent picture of both the inside and the outside of a star. As a result of these studies, combined with the results of observational astrophysics, we may now speak with some confidence of the following broad facts concerning stars.

1. The stars range in diameter from around 500,000,000 km. to about 20,000 km.

2. The masses of the stars show a less drastic variation from the mean. The most massive stars are from 100 to 200 times the sun while the so-called white dwarfs are from 1/5 to 1/10 the solar mass.

3. While the densities of the outer layers are of the order of 10^{-4} atmosphere or less, the density of the deep interior is always quite large. A good mean value of the central density would probably be of the order of 100 g. per c.c. but for the white dwarfs it may be as great as 10^6 g. per c.c.

4. In spite of these great densities, the temperatures in the deep interiors of stars are so high (of the order of 30,000,000°K.) that the stars are believed to

be gaseous throughout their volumes right to the centre. The term gaseous means that the material of the stellar volume behaves approximately as a perfect gas and this is possible because the atoms are highly ionized so that the electrons and the atomic nuclei together constitute the molecular units of the gas.

5. The central temperatures, which, as has already been mentioned, are of the general order of 20 to 50 million degrees, not only make possible the existence in a gaseous state of matter at great densities but the resulting pressure of radiation is so great that it is an important factor in maintaining the equilibrium of the star and preventing it from collapsing by its own weight.

From the point of view of the present discussion, the most important fact of this brief summary is that stars are completely gaseous bodies with no such sharp distinction between atmosphere and inner surface as is found, say, on the earth or the other planets. In a certain sense it might be correct to say that a star is all atmosphere, although it is necessary to distinguish between the different layers, in any quantitative discussion of observed phenomena. For purposes of clarity, we shall, therefore, arbitrarily restrict the atmosphere to that part of the star which is susceptible to direct observation by optical methods.

Consider the optical thickness of a stellar atmosphere as defined by the equation

$$I_\lambda = I_{0\lambda} 10^{-\tau}. \qquad (1)$$

Here $I_{o\lambda}$ is the intensity of stellar radiation at optical depth τ and I_λ is the intensity reaching the observer. It will be noted that increasing values of τ lead to smaller and smaller values of I_λ though there is theoretically no limit beyond which observations cannot penetrate. Most actual astrophysical observations, however, will be concerned with optical depths less than 3 and for most practical purposes the depth of the stellar atmosphere may be defined in this way. Since τ is a function of λ the linear extent of the observable atmosphere will depend upon the wave-length of the radiation involved.

The actual linear depth of a stellar atmosphere is thus never known with any degree of certainty though we are accustomed to think in terms of depths of thousands or even hundreds of thousands of kilometres. Of one point, however, we may be reasonably certain; for an ordinary absorption line star the depth of the observable stellar atmosphere is an insignificant fraction of the radius of the star as a whole.

Classification

Since this contribution is restricted to the hotter stars it seems well to make a brief reference to the subject of classification. The Harvard system divides the stars into the classes W, O, B, A, F, G, K, M, N, R, S, representing, as we shall see later, a temperature scale ranging from approximately 100,000°K. to 2,000°K. Roughly speaking the hotter stars may be placed in the range having temperatures greater than 10,000°. This will include the early A's and all stars of earlier spectral class.

Stark Effects in Stellar Spectra

One of the most interesting phenomena of stellar spectroscopy is the tremendous width of hydrogen lines in certain A-type stars, especially when these widths are contrasted with narrow metallic lines observed in the same spectra. In figure 1 is shown the line Hγ of α^2 Geminorum which has a width of 200 angstroms, while clearly visible on the same spectrum are numerous metallic lines which are relatively fine and narrow. Another type of observation of almost equal interest is found in the fact that not all hydrogen lines of A-type stars exhibit the phenomenon of broad lines. In figure 1 are shown also profiles of Hγ for θ Aurigae and H.D. 223385 as well as α^2 Geminorum. These three stars are all of early A-type and yet the line-widths show a progressive decrease in passing from α^2 Geminorum to H.D. 223385. R. M. Petrie[6] has discussed this phenomenon and has shown that the hydrogen line-width is closely correlated with the intrinsic luminosity of the stars, wide lines being associated with stars of low luminosity and vice versa. The very luminous star H.D. 223385 is approximately 900 times as bright as α^2 Geminorum and 175 times as bright as θ Aurigae.

There is now little ambiguity attaching to the nature of the wide hydrogen lines of A-type stars. A logical explanation is found in Stark effect due to the electric fields which are present during the close approaches of radiating atoms to charged ions in a highly ionized stellar atmosphere.

The dependence of the absorption coefficient on the density and electron pressure is illustrated in equation 2 due to Unsöld[7] and Holtzmark,[8]

$$\sigma = \frac{CF_0^{3/2}}{\Delta\lambda^{5/2}}, \tag{2}$$

where F_0, the average field, has the following dependence on the electron pressure

$$F_0 = 46.8\left(\frac{P_e}{T}\right)^{2/3}. \tag{3}$$

Here $\Delta\gamma$ is the half width of the observed hydrogen line, P_e is the electron pressure and T is the temperature of the stellar atmosphere.

The observed correlation between line-width and absolute magnitude is thus readily explicable in terms of Stark effect. In a dwarf star of low absolute magnitude, the value of surface gravity is relatively high. The gas pressure and electron pressure are correspondingly high providing conditions favourable for the close approach of atoms and ions during radiation and absorption processes. For a star of large absolute magnitude, the reverse is the case, the density and electron pressure are lower and the average field strength is less due to less frequent encounters of atoms and ions.

Of the atoms other than hydrogen, the only one likely to exhibit Stark effect of observable magnitude is helium. The line displacements, however, are in general only half those expected for hydrogen and since the abundance of neutral helium in the B-type stars is very much smaller than that of hydrogen in the early A's, the effects are more difficult to observe. Three general types of effects may be expected:

1. For stars where the lines are sufficiently narrow, it may be expected that Stark effect will widen or distort the profile in a more or less predictable manner, usually in an unsymmetrical way.

2. The existence of electric fields may be expected to result in the appearance of certain forbidden transitions known as electric combination lines, the position of which may be predicted from atomic theory. They should in general be immediately to the violet of the normal line position.

3. For stars where the detailed line profiles are obscured by rotational broadening, the Stark effect may show itself by an anomalous distribution of intensity in the various helium series since the effect of electric fields is not the same for lines of different series numbers.

Since for a number of reasons, it is more difficult to draw general conclusions from (3) our present discussion will be confined to (1) and (2).

In actual observations (1) and (2) ordinarily act together, the Stark effect on the normal line producing a line unsymmetrically extended to the red while the electric combination lines which appear

immediately to the violet of the normal line, extend it unsymmetrically to the violet. The net result may be a stellar line which approaches symmetry quite closely and which suggests a miniature of the broadened hydrogen profiles. For a few stars with lines sufficiently sharp, however, what appear to be the electric combination lines are present as definitely observable minima to the violet of the normal line position. This was at first regarded[9] as indisputable evidence of the presence of helium Stark effect in stellar spectra but later studies by Foster and Douglas[10] and by Underhill and Petrie[11] showed that their minima did not appear in the predicted position and this has introduced a considerable element of uncertainty. Both the broadened helium profiles and the satellite lines are clearly shown in the above-mentioned paper by Foster and Douglas and in a more recent article describing the helium line profiles in B-type stars by Underhill.[11a] The present position with regard to helium Stark effect in stellar atmospheres is, therefore, not entirely satisfactory. Few astrophysicists would doubt its existence, but the observed phenomena have not been completely explained and it is possible that further astrophysical studies of this phenomenon will lead to new knowledge concerning the effects of electric fields on radiating or absorbing atoms.

Motions in Stellar Atmospheres

Apart from temperature agitations common to all assemblages of atoms or molecules there are several types of motions in the atmospheres of stars which are revealed by studies of stellar spectra. The first of these is rotation of the star as a whole. The existence of rotation among bodies of stellar and planetary character seems well nigh universal and has numerous examples in the solar system. The existence of spectroscopic and visual binary stars is another clear indication of rotation among celestial bodies. Further, a close examination of the phenomena of eclipsing binaries shows clearly that in some instances the rotation of the component stars is more rapid than that indicated by the period of the binary system as a whole.

Quite apart from studies of binaries there is very good evidence from the spectra of individual objects that most early type stars are in a state of rapid rotation. This is indicated by a broadening and

flattening of the stellar line profiles which is more marked as the rotation increases.

The velocity in the line of sight of any point on a stellar disc is given by the formula:

$$V = \omega r_1 \sin i, \tag{4}$$

Where ω is the angular velocity of rotation, r_1 is the projection on the disc of the distance from the point considered to the axis of rotation and i is the inclination of the axis of rotation to the line of sight.

The effect which rotation of the star will have on an absorption line may be found by integrating over the disc on the basis of an assumed initial form of the line. Such calculations have been carried out by Struve[12] and Carroll[13] who have shown that the broadened forms of many stellar lines are due to rotation. The velocities in the line of sight due to rotation may range from a few tens to several hundred km./sec. depending on the velocity of rotation and the inclination of the axis of rotation.

The rotational broadening approaches zero for small values of the angle i and it is generally supposed that early type stars with sharp lines have their axes of rotation closely coinciding with the line of sight. On this assumption the proportion of narrow-lined stars is readily calculable and the observations are closely in agreement with prediction.

For the most part, relatively little attention has been paid to rotation as a major influence on the physics of the stellar atmosphere but there may well be some instances where the centrifugal force of rotation is sufficient to upset normal equilibrium and cause the streaming out of matter from the equatorial plane. Various phenomena of stellar emission have been attributed to this cause by Struve and it may be that it is in part responsible for the existence of the large group of B-type emission line stars.

Another type of motion in stellar atmospheres which is known to exist but which depends on somewhat less clear-cut observational evidence is turbulence. Turbulence, as distinguished from temperature motions of individual atoms, may be defined as the motion of groups of atoms which may in some instances constitute quite large volumes of the stellar gas. As might be expected, line profiles due to turbulence have an exponential form of the general character of equation 5.[14]

$$\sigma = \text{const. } e^{-\left(\frac{v}{v_0}\right)^2} . \qquad (5)$$

Here σ is the absorption coefficient corresponding to a particular velocity displacement v in the line, and v_0 is the mean velocity due to turbulent or temperature motions of the gas molecules.

It is somewhat difficult to distinguish effects due to turbulence from those caused by rotation. They both lead to a broadened and flattened character to the centre of the line and although the wings are different the distinction may observationally be none too clear especially where both effects may be present in a single star.

For various late type stars the presence of turbulence has been inferred from studies of the curve of growth, the Doppler portion of the curve being extended beyond that which could be due to temperature motions alone. So far such methods have been less used for early type objects and so present ideas on turbulence in these stars are based on such evidence as is available from line profiles and on the conviction that high surface temperatures provide favourable conditions for the development of turbulent motions.

Both stellar rotation and turbulence are a nuisance to the stellar spectroscopist who is trying to carry out a detailed analysis of other aspects of a stellar atmosphere. They cause widening of the lines and make it difficult to detect the details of structure due, say, to electric or magnetic fields. This is particularly the case for studies in the very interesting field of stellar magnetism[15] and the number of early type stars with lines sufficiently sharp for studies of this kind is very small. Fortunately, the almost universal existence of rapid rotation in early type stars makes it possible to be reasonably sure of the orientation of the axis of rotation for those objects which do have fine lines.

The type of stellar atmospheric pulsation affecting the volume of the atmosphere as a whole and known as Cepheid variation[16] is well known to all and it is not proposed to discuss it in any detail in this review. This type of atmospheric motion is mainly characteristic of the later type stars. The periods of such pulsations vary from 1/2 day to 100 days and the magnitude of the velocity variations are usually of the order of 20 km. per sec. There are a few early type stars which exhibit this type of motion, the best known example being H.D. 199140.* In this star the period is 0.4 day and the mag-

*Unpublished work of R. M. Petrie.

nitudes of the velocities involved are ± 60 km./sec. which in anything but a star would be considered to be a phenomenon of explosive violence.

In addition to rotation, turbulence and pulsation, another very important type of motion in stellar atmospheres is the actual large scale ejection of material from the stellar surface into outside space. Even though the evidence is for the most part indirect, most students of the sun and its effects on earthly conditions now believe that at times there is fairly large scale ejection of atoms from the solar surface. The agency involved in the main is believed to be radiation pressure augmented by the existence of hot spots on the sun's surface. Since this phenomenon is reasonably well established for the sun, it would appear logical to suppose that the high surface temperatures of early type stars would give rise to effects similar in kind but of a more violent character.

The first definite spectroscopic evidence for the ejection of gases from a stellar surface was found for the novae where it has been established that the tremendous increase in brightness is accompanied by the throwing off of gaseous layers from the surface with velocities which are sometimes as great as three or four thousand kilometres per second. Evidence for these velocities is found in the positions of the absorption lines of the Balmer series which are sometimes displaced to the violet by as much as 60 angstroms, corresponding to a Doppler effect of 4000 km./sec.[17] The effect is illustrated in figure 2, showing the spectrum of Nova Herculis on Feb. 3, 1935.

It will be noted that there are no corresponding absorption lines to the red and that numerous atoms in the spectrum in addition to the Balmer series are similarly affected so that the interpretation of the observations is scarcely in doubt. To make the matter more certain actual increases in the observed diameter of the star in agreement with the velocities derived from the spectra have been recorded for certain novae whose distances are known. Spectroscopic evidence of an essentially similar kind indicates that large-scale ejection of material takes place from the atmospheres of the Wolf-Rayet and P Cygni stars also. For the Wolf-Rayet stars, illustrated in figure 3, the displacement to the violet of the absorption lines corresponds in general to velocities from 1000 to 4000 km./sec. For the P Cygni stars, tracings of whose spectra are illustrated in figure 4, the ejection

velocities are generally a few hundred km./sec.[19] These displaced absorption lines are commonly interpreted as due to the ejection of gases and the bright lines which accompany them are believed to arise in the envelope of ejected atoms which surrounds the star. For most early type stars which exhibit this phenomenon the velocity of ejection exceeds the parabolic velocity of escape so that the material is eventually lost to the star.

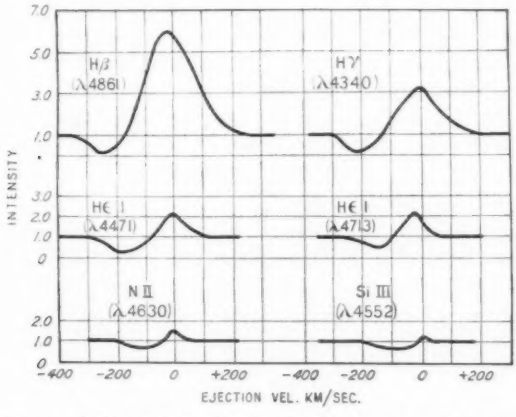

Fig. 4. Intensity Profiles of P Cygni Lines. In this figure intensity is plotted against velocity for a number of lines in the spectrum of the star P Cygni. The figure illustrates the relative intensities of absorption and emission components and the difference in the ejection velocity from line to line.

Although only for the types of stars mentioned above is the fact of ejection established by direct spectroscopic evidence, it is probable that it is a feature of all early type stars. While, as has already been suggested, the process may be assisted in some instances by the centrifugal force of rapid rotation, the major accelerating force probably has its origin in the high temperature of the stellar surface which acts either through direct radiation pressure or in some other manner not now fully understood.

Temperatures of Absorption Line Stars

The Continuous Spectrum. So many of the characteristics of a stellar atmosphere are dependent on its temperature that determinations of this quantity by direct or indirect means are of major

importance in this branch of astrophysics. The initial approach to the problem of stellar temperature is to regard the star as a black body which radiates according to Planck's formula as expressed in the equation.

$$E_\lambda = \frac{c_1 \lambda^{-5}}{e^{\frac{c_2}{\lambda T}} - 1}, \tag{6}$$

where $c_1 = 3.71 \times 10^{-5}$ λ, wave-length in cm.
$c_2 = 1.435$ e, base of nat. logs.
E_λ, radiant energy of wave-length λ

Making use of this formula it is possible to derive Wien's law for the wave-length of radiation of maximum intensity

$$\lambda_m = \frac{0.289}{T} \text{ cm.}, \tag{7}$$

and also Stefan's law for the total quantity of radiation in all wave-lengths emitted by a star of given diameter and temperature

$$E = 5.72 \times 10^{-4} T^5. \tag{8}$$

(E = ergs per sec. per sq. cm.)

While theoretically either of these two quantities can be used for the determination of temperature, actually for the early type stars most of the radiation is in the far ultra-violet which cannot be directly observed. As a consequence Wien's law becomes impossible of application.

It is possible to make an estimate of the total radiation and to derive the so-called effective temperature but the fact that most of the radiation is in a region inaccessible to observation makes this difficult and the matter is further complicated by uncertainty in the distances and intrinsic luminosities which are necessary for this method of estimating temperature.

In general, therefore, the application of Planck's law to studies of the continuous spectrum is limited to comparisons of the slope of the energy curve in the observable region of the spectrum (expressed in units of $1/\lambda$) with that of a body of known temperature.[19a] For relative values, standard stars may be used but for absolute determinations of temperature a terrestrial source is necessary. Unfortunately there are difficulties in applying these methods to stars and they may be listed as follows:

1. Owing to the presence of absorption lines and of absorption at the limits of optical spectral series, such as the Balmer series of hydrogen, it is known that stars show deviations from black body radiation and these deviations from black body laws may introduce considerable errors into temperature determinations.

2. For early type stars with temperatures in excess of 20,000°K. the change of slope of the energy curve with temperature is so small as to make the method difficult of application.

3. In comparisons with a terrestrial source and to a lesser extent for intercomparisons of stars the variable absorption of the earth's atmosphere is difficult to allow for with precision. Atmospheric absorption not only varies with altitude, but it also varies from night to night and even from moment to moment, introducing an unavoidable source of uncertainty into gradient measurements.

4. Finally for the early type stars, which are mostly fairly distant, a major disturbing factor is found in the differential absorption of light by interstellar matter. General absorption by interstellar material is believed to be due to small particles of the order of 10^{-5} cm. diameter and it has been shown that the law of absorption varies with wave-length according to a law which, is expressed in the following equation

$$\sigma = \text{Const.} \times \lambda^{-1}. \tag{9}$$

W. Petrie[20] has recently made an attempt to derive stellar gradients for a number of early type stars by eliminating the absorption of interstellar matter on the basis of distances derived from intersteilar line intensities. He concluded that interstellar material, whether gas or dust, is too irregularly distributed for such a method to be successful and that only nearby stars can be dealt with in this way.

It will be understood of course that in spite of the above-mentioned difficulties there have been many determinations of temperature by the observation of gradients and a temperature scale has been worked out which indicates temperatures of 10,000° to 14,000° for the early A-stars to 30,000° for the hotter O's. It is questionable, however, on the basis of the direct application of Planck's law to the observable continuous spectrum whether we know the temperature of the A0 stars, which form the reference point for the early type stars as a group, to an accuracy of better than 3000° to 5000°. It is, therefore, necessary to turn to other methods if we wish to have values of temperature in which we can place full confidence.

Ionization in Stellar Atmospheres. A very superficial examination of the spectra of the early type stars will reveal the presence of absorption lines due to atoms of high ionization potential such as HeI, HeII, OII, OIII, NII, NIII, NIV, NV, CII, CIII, CIV and many others. The general type of relationship which exists between

temperature, density and state of ionization in a normal star is expressed in the following equation due to Saha[21]

$$\log \frac{N_1}{N_0} = -\frac{5040}{T}(I.P.) + 2.5 \log T - 0.48 + \log \frac{2B_1}{B_0} - \log P_e. \quad (10)$$

N_0 and N_1 are numbers of atoms in neutral and ionized states respectively. B is a partition function while P_e is the electron pressure which depends largely on the density of the atmosphere. $I.P.$ and T are of course ionization potential and temperature. It is of some interest to point out that formulae of this general character were first used in studies of the state of ionization of chemical solutions.

The problem of using formulae of this type to deduce the temperatures of stellar atmospheres is quite an old one. In the early studies by Saha, Fowler and Milne,[22] Payne[23] and others only eye-estimates of line intensities were available and efforts were directed toward finding a suitable relationship between the temperature of the star and the presence of lines of a certain atom or ion either at maximum intensity or marginal appearance. Both of these points were difficult to determine accurately and the latter especially was very dependent on the quality and dispersion of the available spectra.

Many of these difficulties have been avoided in a recent investigation by R. M. Petrie[24] who has utilized precise spectrophotometric measures of the intensities of lines of HeI and HeII as his observational data. Petrie has shown that by suitably combining Boltzmann's formula for the distribution of atoms in excited states

$$\frac{N_a}{N_o} = \frac{w}{B_0(T)} e^{\frac{-X}{kT}}, \quad (11)$$

N_0 total number of atoms, N_a atoms in excited state

X excitation potential, B_0 partition function w statistical weight.

with the previous Saha equation, it is possible to express the stellar temperature in terms of the ratio of lines of HeI and HeII in the spectrum. The relationship is shown in equation (12) below.

$$\log R = \log \frac{n_b}{n_a} + \log \frac{N_1}{N_0}. \quad (12)$$

n_a and n_b are proportions of neutral and ionized atoms respectively in excited states producing lines.

Petrie has made use of the line λ 4471 of HeI and λ 4542 of HeII since these lines are situated relatively close to one another in the spectrum and their relative intensities are easy to obtain with the necessary precision. The principal difficulty is in relating the actual observed line intensities with the numbers of atoms producing the lines. This difficulty has been at least partially overcome by studies of the curve of growth for helium by Goldberg indicating the numbers of atoms producing lines of known intensity. On this basis Petrie has derived the relative numbers of atoms producing these lines of HeI and HeII and has utilized equation (12) to determine temperatures for the O and early B-type stars. The values of 28,600° for B0 and 36,300° for O5 are probably the most accurate now available for stars of this class.

Temperatures of the Emission Line Stars

Turning now to the emission line objects it may be pointed out that they offer a new approach to the problems of the temperatures of very hot stars. The first studies of stars of this type were made by Zanstra in connection with the planetary nebulae. A planetary nebula consists of a great globe of gas of as much as several light-years in diameter illuminated by a star in its centre which appears always to be of very high temperature. A study of the spectra reveals the fact be of very high temperature. A study of the spectra of these objects reveals the fact that in general the spectrum of the star is continuous while that of the gaseous envelope surrounding it consists of bright lines due to atoms of high ionization potential. Among prominent lines in the spectra of planetary nebulae are those due to H, HeI, HeII, OIII and NIII.

A striking feature of the planetary nebulae, as illustrated in figure 5 which shows the Ring Nebula in Lyra, is the large value of the integrated luminosity of the nebula as compared with that of the central star. A quantitative study of this phenomena by Zanstra[25] showed that this could be explained as a fluorescence process in which the ultra-violet light from the hot star was absorbed by the nebula and converted into visible luminosity. The mechanism of absorption is considered to be photoelectric ionization of the atoms of the nebula by that portion of the continuous spectrum beyond the ionizing frequency of the atom concerned. For hydrogen this

is at wave-length 912A. and for atoms of higher ionization potential it will be of correspondingly shorter wave-length. In a steady state the number of captures will equal the number of ionizations and those electrons captured in upper states will subsequently cascade to lower levels giving rise to observable emission.

The amount of radiation available for ionization will depend on the temperature of the central star and the numerical relations may be expressed in terms of the following equations due to Zanstra

$$\int_{x_0}^{\infty} \frac{x^2}{e^x - 1}\, dx = \sum \frac{x^3}{e^x - 1} A_\nu . \qquad (13)$$

$$x = \frac{h_\nu}{kT}, \qquad x_0 = \frac{h_{\nu 0}}{kT}$$

A_ν is an observed quantity depending on the observed strength of the line. The left hand member of this equation represents the number of quanta of ultra-violet starlight absorbed by the envelope, while the right hand member represents the number of quanta emitted as observable emission lines.

Zanstra's theory of nebular luminosity, embodied in the above equation, represents a very important advance in our knowledge of early type stars since it makes possible estimates of the temperatures of the nuclei of planetary nebulae, objects which cannot, in general, be successfully studied by other methods. It will be noted that equation (13) involves the stellar temperature and that it can easily be solved by trial yielding the temperature of the central star.

Results of the study of a number of these objects by Zanstra and others have indicated that the planetary nuclei range in temperature from 30,000° to 140,000°K.

In addition to the planetary nebulae there are many other stars which show emission lines but which are not accompanied by shells of gas large enough to be directly observed. Among stars of this type are the novae or new stars which are actually old stars which suddenly attain a new lease of life and blaze up brilliantly for a relatively brief period only to subside to their former low luminosity after a few months or years. One of the phenomena associated with a nova's rise to brightness, as has already been pointed out, is the displacement of its absorption lines to the violet by amounts corresponding to velocities of several thousand kilometres per second.

Since these velocities are larger than the velocity of escape, the gases at the surface must be escaping from the star to form around it an envelope of outward moving gases which has some of the characteristics of a planetary nebula. Actually in a few cases novae have been near enough for an actual disc to be seen, giving ample confirmation to this interpretation, and it might reasonably be expected that if the temperature of the central star is sufficiently high emission lines would be observed.

Actually emission lines are a conspicuous feature of all nova spectra and they increase in intensity after maximum light when the nova is known to increase in temperature. There now appears to be no question but that the origin of these lines is similar to those of planetary nebulae and the relation between line intensity and the temperature of the exciting star can be derived by Zanstra's equation quoted above. The use of this equation makes it possible to follow the temperature of the nova from 20,000° near maximum light to approximately 100,000° when the emission bands reach their greatest intensity.

In addition to the novae there are numerous other stars which exhibit emission lines or bands but which do not exhibit major changes in luminosity of the kind shown by the novae. The Wolf-Rayet stars, spectra of which are shown in figure 3, are characterized by broad emission lines of great intensity due to highly ionized atoms, and the emission bands are accompanied by absorption borders on their violet edges. It therefore appears that these stars also must be surrounded by envelopes of ejected gases and that their temperatures may be derived by the methods already mentioned. Such determinations indicate temperatures for the Wolf-Rayet stars ranging from 50,000°K. to 100,000°K.

The P Cygni stars, profiles of which are illustrated in figure 4, are in many ways similar to those of Wolf-Rayet type except that the displaced absorption components are more intense relative to the emission and the velocities of ejection are much less, of the order of a few hundred kilometres per second. The application of Zanstra's equation to the emission line intensities leads to values of temperature ranging from 10,000° to 42,000°.[27]

In addition to the types of stars mentioned above, whose spectra give definite evidence of the type of motion required to produce an envelope of gases around them, there are numerous other early type

stars which also show emission lines. Spectra of two stars of this type are illustrated in figure 6. Mainly by analogy with the emission line objects already described, it is now generally believed that the emission lines in these objects also arise in an envelope of diffuse gases surrounding the star. Fortunately in one or two instances of eclipsing stars there is independent evidence supporting this view. For the star RW Tauri, Joy[25] has observed that the spectrum is ordinarily of absorption type, but at times of total eclipse of the brighter component by a cooler companion, emission lines appear conspicuously, indicating the presence of a gaseous envelope of considerably greater diameter than the primary star. In addition, certain of these objects during the passage into or out of total eclipse exhibit rotation effects associated with the emission lines which are consistent with the idea that the emission lines originate in a diffuse envelope which rotates with the star.

For many years, the origin of emission lines in early type stars was an unsolved mystery and the recognition that such lines are due to an extended gaseous envelope illuminated by a hot star is in itself an interesting development in astrophysical science. Of considerably greater importance, however, is the possibility of shedding additional light on the nature of the stellar sequence as a whole. The main effort in astrophysical research has always been concentrated on the absorption line stars since they outnumber the emission line stars by approximately one thousand to one. The emission line stars have sometimes been referred to as pathological cases with the implication that astrophysical results derived from them are of less general validity or application than for the more normal absorption line objects.

While this may be so, it may be pointed out that the study of abnormal psychology has often led to advances in knowledge concerning the mental processes of normal human beings. Similarly with stars, the study of the supposedly abnormal emission line objects may lead to valuable information concerning the stellar sequence as a whole and I should like to conclude this discussion by drawing your attention to an instance of this character.

A good many otherwise normal absorption line stars have a few emission lines associated with them while others, especially among the P Cygni stars with conspicuous emission, have sufficiently well developed absorption line spectra to place them with reasonable

definiteness in their proper place in the Harvard system of classification. For these stars as well as for others of more completely developed emission line characteristics, it is possible to utilize measured emission line intensities to determine stellar temperatures on the basis of Zanstra's equation. Since sporadic emission lines are found in all the early type classes down to and including the early A's, it is possible to draw up a scale of temperatures for the entire range of early type stars based on emission line character alone.

Such a temperature scale is shown in the Table. Here Zanstra's temperatures are used for the planetary nebulae, the results of Beals are used for the Wolf-Rayet stars, while values derived by Beals and Hatcher[26] are used for the P Cygni stars which cover the O, B and early A-stars. For purposes of comparison, the table also includes the ionization temperatures derived by Petrie for the absorption O's and the colour temperatures of the B's and early A's by the Greenwich observers.[27] The agreement is on the whole very good, and suggests that we now have, for the early type stars as a whole, a temperature scale in which we may have reasonable confidence.

TEMPERATURE SCALE
EARLY TYPE STARS

Class	Temperature° K.		
	Absorption Lines and Continuous Spectrum	Emission Lines	Adopted
Planetary Nebulae		140,000 to 30,000	140,000 to 30,000
W5		110,000	110,000
W8		50,000	50,000
O5	36,300	40,000	38,000
O9	30,700	34,000	32,000
B0	25,000	32,500	28,000
B9	13,500	17,000	15,000
A0	14,000	16,000	14,000
A4	11,000	11,000	11,000

One of the aspects of this table which cannot fail to attract attention is the position occupied by W stars and the planetary nebulae relative to the other early type stars. Considered on the basis of temperature alone it would appear that these interesting emission line objects simply represent an extension toward earlier spectral types of the normal Harvard sequence of absorption line stars. The possibility that this may actually be the case receives support from the fact that no absorption line stars have been definitely observed in the temperature range from 40,000° to 100,000°K. It is also well known that the tendency for the stars to exhibit emission line spectra is greater for increasing temperature. Although the absolute number of emission line objects is greater for the B's the proportionate number is greater in the O class. If this proportion of emission to absorption line objects changes with sufficient abruptness at about O5 in the sequence then it may be permissible to regard the W stars as a normal part of the Harvard sequence and their emission line character as a consequence largely if not entirely of their higher temperatures.

For temperatures above 50,000° therefore, it is suggested that the normal type of stellar spectrum may be of emission type just as for lower temperatures the normal spectrum is of absorption line character.

As for the planetary nuclei it may be pointed out that some of them appear to be ordinary O-type stars, while others exhibit Wolf-Rayet bands in no way different from other W stars. There are, however, a number of the hotter planetary nuclei which, insofar as the writer is aware, have neither Wolf-Rayet bands or absorption lines in their spectra. The strong emission lines which characterize the spectra of the gaseous nebulae which surround them make it difficult to be certain of the presence or absence of absorption lines but present indications are that they are either not present or are of very low intensity.

Little that is definite can be said at present about the interesting question as to their relation to the Wolf-Rayet stars. It appears, however, that the two types of objects are roughly parallel as regards temperature and it may be that the relations between them are in a general way similar to those existing between the absorption and emission line objects in the O and B classes. The writer believes that the most helpful approach to the problem at the present time is to regard the entire group as a normal extension of the Harvard sequence and to see whether the methods of theoretical astrophysics may not give an indication of the types of spectra to be expected for

a reasonable range of masses diameters and chemical compositions. Some interesting suggestions along this line have recently been given by Miss Anne Underhill[29] who has indicated the probability that the effects of radiation pressure will render unstable the atmospheres of most stars of temperature greater than 50,000°. It seems possible that a further application of the same methods might shed some light on the origin of the observed differences between the spectra of the W stars and the nuclei of the hotter planetaries.

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OUT OF OLD BOOKS

By Helen Sawyer Hogg

Blue Sun

Inhabitants of southern Ontario were startled on Sunday, September 25, 1950 at a brief glimpse of the sun as a pale, bluish-mauve disc. At the same time the western sky became a dark, terrifying mass of cloud and haze, as though a gigantic storm were approaching, while to the north and east the sky toward the horizon was a clear steel-blue. The darkness was so marked at 3:30 in the afternoon that the writer observed a group of six wild ducks going to sleep quietly in the middle of a pond, with their heads nodding or tucked under their wings.

On the following day, Monday, September 26, the celestial phenomena were remarkable in a heavy haze or dry fog which permeated the whole sky. In the afternoon for several hours, at least in the region around Toronto, the blue-mauve sun could be seen in the heavens, casting no shadow and shining without rays.

We learned on Sunday even as the eerie darkness descended, that all this was attributable to smoke from heavy muskeg fires in distant Alberta, two thousand miles away. In subsequent days the smoke pall moved eastward, causing similar phenomena to be seen in eastern Canada and the United States, and in the British Isles several days later.

It should be noted that this remarkable apparition of a blue sun was missed by many people. Since the light was so dim, a casual observer would think that the sun was completely obscured. Only if one's glance was directed to the sky was one rewarded with a sight which few of us had ever previously seen. Many people for the first time became acquainted with the fact that the old expression "once in a blue moon" had a basis in scientific fact, designating an event which is likely to occur only once in a lifetime.

Unfortunately the haze and clouds were so heavy that the eclipse of the moon was clouded out in the Toronto region except for occasional glimpses, and no blue moon was observed here.

Now that we have had the good fortune to experience a blue sun, it is interesting to look back at other records of coloured appearances of the sun or moon. Reference to a blue moon has already

been made in this column, (this JOURNAL, vol. XL, p. 164, 1946) in connection with the great explosion of Krakatoa in 1883, which gave the world the greatest spectacle of coloured suns and moons that has ever been recorded. These reports were gathered together and summarized in the splendid volume "The Eruption of Krakatoa, and Subsequent Phenomena," the Report of the Krakatoa Committee of the Royal Society, London, 1888. A whole section of this volume, by Mr. E. Douglas Archibald, is devoted to "The Blue, Green, and Otherwise Coloured Appearances of the Sun and Moon in 1883-84."

The violent eruption of Krakatoa occurred on August 26-27, 1883. The weird and beautiful sky phenomena resulting from the cloud of dust and ash hurled into the atmosphere lasted for many months over most of the earth. The coloured suns and moons, however, were confined to the tropical regions, and were remarkable in that the appearances of the blue sun travelled around the earth from east to west in thirteen days, making two complete circuits of the world before the dust had dissipated in the atmosphere. The sun was not constant in its colouring. Though it was usually described as green or blue in the tropical regions, metallic descriptions were also applied to it, as coppery, silvery, or leaden. In the above-mentioned section we read that

> It appears that the "blue" sun was chiefly seen at great distances from Java. - - - The "green" sun was visible at first only in the Indian Ocean, but afterwards more generally than either of the other colours, and finally the "silvery sun", when at a high altitude, appears to have been almost entirely confined to a narrow zone near the Equator, and more especially on its southern side. If to this we add the cases in which the sun appeared coppery, dim, and sensibly obscured, we find that they were all close to the Equator in each hemisphere.

At any one place the colour of the sun was not necessarily constant during the day, but varied markedly with altitude. A fine description of this phenomenon is given by a Government officer who was travelling in Ceylon from Mannâr to Trincomalee, September 12th, 1883.

> The sun for the last three days rises in a splendid green when visible, *i.e.*, about 10° above the horizon. As he advances he assumes a beautiful blue, and as he comes further on looks a brilliant blue, resembling burning sulphur. When about 45° it is not possible to look at him with the naked eye; but even when at the zenith the light is blue, varying from a pale blue to a light blue later on, somewhat similar to moonlight, even at midday. Then, as he declines,

the sun assumes the same changes, but *vice versa*. The moon, now visible in the afternoons, looks also tinged with blue after sunset, and as she declines assumes a very fiery colour 30° from the zenith.

In the same volume the Hon. Rollo Russell traces the geographical course of the coloured suns, as well as of the peculiar sky glows, and shows how the coloured sun phenomena actually circled the earth twice, going from east to west with velocity of more than seventy miles an hour. The first records of a green sun came from Batavia and Ceylon on the 27th of August and must have been caused by a heavy current of thick dust, moving northward from the eruption.

The mass of the ejecta was carried with great velocity westwards and south-westwards at a very high level. - - - The green sun of the 27th at Ceylon and Labuan lasted only a short time, and was not generally observed in any large area. In fact, the absence of green or blue suns in the Indian Ocean before September 8th deserves particular notice. - - - On September 1st the blue sun band extended across the Atlantic from east to west, reaching even to Guayaquil at 80° W. in the latitude of 2° S.; and between 12°.7 S. 27°.3 W. and 10° 40′ N. 26° 30′ N. in the mid-Atlantic. - - -

On September 2nd the whole northern part of South America, between the Antilles and Peru, and between Panama and Paramaribo, seems to have had a blue sun; - - - South of the Equator there is little mention of a blue sun, but much of a persistent grey haze in the upper air. - - - On September 5th the zone of blue or green sun in the Pacific reached as far north as 21° 30′ N. for a short time, and southward at least as far as 13° 17′ S., and in breadth was wider than hitherto. - - - From September 9th to 12th a green or blue sun was visible over a great part of India.

There can be no doubt, from a comparison of the data given in the general list, that the blue sun and yellow haze passed round the world from east to west in a gradually widening zone, and that the matter concerned in producing them was unequally distributed in clouds or streams of different density. The wonderful red twilights were seen only where the haze was much thinner, either before the dense main cloud of matter covered the sky, or after it had passed, or at its edges on the northern and southern borders. - - -

The denser part of the main cloud of matter in the first circuit, causing a blue, green, or silvery sun, and a yellow or white haze, covered a much narrower area than the after-glows. In the Indian Ocean it seems to have extended from Diego Garcia to the Seychelles on August 28th—that is, between 20° S. and 5° S., and probably some degrees further north; in the Atlantic, between 10° 40′ N. and 14° S., and in the Pacific between 10° 19′ N. and 13° 17′ S. - - -

On September 9th when the main cloud of matter had reached India after a circuit of the earth, its breadth appears to have been greater in the northern than in the southern hemisphere. A green sun was visible over Southern and Central India on September 10th. - - - On September 22nd the green sun had returned to Southern India after a second circuit of the globe, and lasted two

or three days as before. After this no well-attested observation of a green or blue sun, except at Duem, 14° N. 32° 30′ E. on September 24th, when it rose green, and at 9° S. 35° W. on September 28th, when it set pale blue, occurs in any contemporary record. - - -

On the whole, the tendency of the matter causing the twilight phenomena was to spread northwards and southwards as well as westwards during the rapid circuit of the blue sun matter from east to west within the tropics. - - - We find the northern limit near the end of the first circuit to have been about 22° N. at Honolulu, or 28° north of Krakatoa, and the southern limit about 33° S. at Santiago, or 27° south of Krakatoa. - - - At the end of the second circuit, about September 22nd, the glows may be roughly stated to have extended from between 20° and 30° N., to between 30° and 40° S., but their distribution was not regular within these limits.

This volume also tells of other instances of coloured suns more local in nature. Mr. Archibald remarks that he witnessed a blue sun produced experimentally by Professor Kiessling of Hamburg from a cloud of chloride of ammonium, and from aqueous vapour mixed with ordinary dusty air. He lists several appearances of a blue sun due to dust storms in the Sahara and in central Asia, and at a plant in Eastbourne, England where fine dust rising from stone-crushing operations gives the sun a blue tinge. We might also note that persons living on this continent in the midst of prairie dust storms have seen the sun as a clear pale blue.

Records of blue suns seen over widespread parts of the globe, however, are quite rare. The table near the end of the Krakatoa volume lists all known volcanic explosions since 1500, and unusual atmospheric phenomena. In general there is a close correlation between the two. Records of red and coppery suns and brilliantly coloured twilights are relatively common, but widespread reports of the blue, green, or rayless sun are few in number. Twice before the explosion of Krakatoa in 1883 are there numerous records of a rayless sun, both times after gigantic volcanic explosions. The first was in 1783, the year of two great eruptions, one of Asama, Japan and the other of Skaptar Jökull, Iceland. Again in 1831 was the sun seen as rayless, or blue or violet. There were three major eruptions in this year, as well as several smaller ones, those of Graham's Island, Babujan Islands, and Pichincha being exceedingly noteworthy. In this year, on August 4, at Canajoharie, New York

The sun at 5 p.m. was dim and violet. At Albany, from August 12 to 31, the western sky was deep red after sunset. One afternoon the sun was pale, like the moon, and slightly green. - - -

The extraordinary dry fog of 1831 was observed in the four quarters of the world. It was remarked on the coast of Africa on August 3, at Odessa on August 9, in the south of France and at Paris on August 10, in the United States on August 15, etc. The light of the sun was so much diminished that it was possible to observe its disc all day with the unprotected eye. On the coast of Africa the sun became visible only after passing an altitude of 15° or 20°. M. Rozet, in Algeria, and others in Annapolis, U.S., and in the south of France, saw the solar disc of an azure, greenish, or emerald colour. The sky was never dark at night, and at midnight, even in August, small print could be read in Siberia, at Berlin, Genoa, etc. On August 3, at Berlin, the sun must have been 19° below the horizon when small print was legible at midnight.

Because of the recent blue sun, the unexplained appearance of a blue sun in 1821 takes on added interest. The authors of the Krakatoa volume could find no volcanic explosion to account for it, and apparently did not look for any other cause.

On August 18 a blue sun, seen in London, Sussex, Worcester, etc. There was a haze and the sun looked like quicksilver. At 9.20 on August 18 the blue sun was observed by a great number of persons in the streets. It lasted about half an hour. The atmosphere on the following days was hazy. At Paris, on August 18, the sun at 5 p.m. was enfeebled by dense vapours, and absolutely white.

I suggest that this unexplained blue sun may have been caused by a heavy forest fire on this continent, just as the blue sun of 1950 was so caused. The middle of August is in the forest fire season. I have hunted some early Canadian records for the year 1821 with the hope of finding a reference to such a fire. None has yet been found, but it is possible that one of our readers might come across one. In those early days, however, the burning of some one's shed was thought more worthy of record than the burning of a vast forest.

However, on the microfilm copy of the *Kingston Chronicle* for August 17, 1821, in the University of Toronto library, we read that

the weather during the last three weeks has been uncommonly dry as well as oppressively hot. The ground is parched, and the vegetables in the garden droop and wither from the want of moisture.

Over a certain section of Canada, then, conditions were certainly ripe for a fire which might have caused the blue sun of 1821.

REVIEW OF PUBLICATIONS

Sterne und Sternsysteme, by Wilhelm Becker. Second edition. Pages 418 plus xii, 5¾ by 8¼ inches. Price 30 DM. Published by Theodor Steinkopff, Dresden and Leipzig, 1950.

This is intermediate between a text-book and a researchers' manual. The author gives a general picture of stars and stellar systems, going into a little more detail than do most authors of astronomical text-books.

The book is divided into two main sections. The first is termed, "Das Milchstrassensystem", and is introduced by a chapter on the general properties of stars, such as luminosity, colour, spectral type, etc. Having laid a foundation, the author discusses variable stars, binaries, clusters, and interstellar matter. He concludes the first part with stellar motions, the spatial structure and kinematics and dynamics of Milky Way systems.

The second section is termed, "Die Aussergalaktischen Nebel". This part is the shorter, and includes types of extragalactic nebulae, distances, radial velocities, and the relationship between the latter two. The author concludes with a discussion of the distribution of extragalactic nebulae.

References to original papers are given at the bottom of each page. This is obviously advantageous to professional astronomers and should certainly be of use to amateurs. Too often, amateurs are content to study only the condensed and necessarily incomplete version of a topic given in a text-book, when they could in many cases comprehend and be more stimulated by the original research papers available in astronomical libraries. A large portion of Becker's foot-notes refers to papers in English.

The first edition of "Sterne und Sternsysteme", published during the war, is probably unfamiliar to most of us on this continent. The second edition deals effectively with the relevant astronomical research work completed before 1950.

W. R. Hossack

NOTES AND QUERIES

OBITUARY: MR. CHARLES E. APGAR,

Mr. Charles E. Apgar, who for a number of years furnished tables of the satellites of Jupiter for our OBSERVER'S HANDBOOK and for the JOURNAL, died on August 17th in Westfield, New Jersey.

Mr. Apgar was eighty-five years old at the time of his death. He was a graduate of Wesleyan University, Middletown, Connecticut. For many years he was engaged in financial work—insurance and brokerage—in New York City. His hobbies included radio and astronomy.

He was amongst the pioneers in amateur radio. During World War I he was instrumental in detecting and exposing secret German radio signals, broadcast from a Long Island station. These had been supplying enemy submarines with coded data on allied ship movements.

In astronomy he took great interest in popularization of the subject, by writing, and by working with amateur groups. For the Royal Astronomical Society of Canada each year he prepared the "Phenomena of Jupiter's Satellites", for the OBSERVER'S HANDBOOK. He also developed a graphical scheme for following the motions of the satellites, from which he prepared tables for the JOURNAL. These gave dates on which all Jupiter's satellites appeared on one side of the planet, and the dates on which Jupiter would apparently be accompanied by only one satellite. Invariably Mr. Apgar's neat and accurate copy was the first item to arrive for each succeeding year's HANDBOOK.

The editors had never known Mr. Apgar personally, yet his occasional letters to us we found most stimulating. He thoroughly enjoyed his astronomical hobby, genuinely worked at it, and was always appreciative of the purposes and efforts of our Society. His widow and his daughter, Dr. Virginia Apgar, of Columbia University, have kindly presented a number of his books to the library of the Dunlap Observatory.

F. S. H.

MEETINGS OF THE SOCIETY

AT OTTAWA

March 6, 1950.—The fourth meeting was held on Monday evening, March 6, at the Carleton College Assembly Hall, with the president in the chair. He introduced the speaker for the evening, Professor J. S. Foster, Director of the Radiation Laboratory at McGill University, who spoke about the cyclotron that has recently been put into operation there. Money for the radiation laboratory came from the sale of property at the top of Mount Royal, originally intended as the site of an astronomical observatory. Numerous slides showed the cyclotron being built, and also illustrated explanations of how it works.

Dr. G. Herzberg proposed a vote of thanks to the speaker. The president mentioned that Dr. Helen Hogg would be speaking on "The Milky Way" at the National Museum on March 8, at 8.15 p.m.

March 20, 1950.—The fifth meeting was held on Monday evening, March 20, at the Carleton College Assembly Hall, with the president in the chair. He welcomed the audience, and introduced each of the speakers of the Members' Discussion Panel on Meteoric Astronomy.

Mr. F. W. Matley spoke about "Visual Meteor Observing", mentioning how useful the layman could be in this branch of astronomy. Because meteors are unpredictable the greater the number of observers the better are the results. The best results are obtained when the observers work in fairly large groups, and one person acts as recorder. The speaker showed slides to illustrate his talk, and told of the exact procedure used when observing and recording these meteors.

Mr. Stanley Mott, in speaking on "Fireballs", declared them to be just the same as ordinary meteors, only brighter. As these fireballs are usually seen by inexperienced observers, our descriptions of them come from their reports. A number of slides showed photographs or drawings of fireballs or their trains, whilst the speaker noted the important points in connection with reporting an observation. While there are a number of known annual meteor showers, the most spectacular fireballs appear to have no connection with them.

Dr. T. L. Tanton spoke about meteorites, stressing especially their history and types. These different types were illustrated with slides, which also showed such other features as shape and the effects of weathering.

Wing Commander D. A. MacLulich, Ph.D., spoke on "Meteor Craters", which are formed because the meteor is travelling at such a high speed and is stopped almost instantaneously. The rock beneath the ground rebounds after it has stopped the meteor, and an explosion takes place, such an explosion forming a large crater compared with the size of the original meteor. The crater is circular because the material is thrown out symmetrically, even though the meteor did not strike vertically. Dr. MacLulich mentioned that craters on the moon are interesting because they have not been eroded, nor has the meteor been slowed down by an atmosphere.

Mr. Hoyes Lloyd proposed a vote of thanks to the speakers. The president closed the series of meetings by thanking all the speakers, lantern operators and others who had assisted, as well as those at Carleton College who had been so helpful in arranging the use of the hall.

MARGARET ANN MCKEE, *Assistant Secretary.*

AT TORONTO

March 7, 1950.—The meeting was held in McLennan Physics Laboratory, the Chairman being Mr. A. R. Clute, President.

Mr. O. S. Hall was elected to membership, and two persons were nominated for membership in the Society.

The speaker, Dr. Martin Schwarzschild of Princeton Observatory, was introduced by the President.

Dr. Schwarzschild's subject was, "Storms on Stars". The ideal star is calm. While spots may be ignored as special phenomena, the all over "rice-grain" texture must be considered in building up a theory. The granules on the sun average about 1,000 miles across. They are areas which are hotter than the darker regions. A comparison was made between the solar weather map and earth's weather map. Terrestrial weather conditions change in a period of a few days. Solar granules sometimes appear and disappear in a matter of a few minutes. This indicates that the solar winds move very rapidly. They average about 5,000 miles per hour.

Richardson and Schwarzschild endeavoured to obtain a direct check on this statement by measuring the Doppler shift of the gases with a spectrograph, and hence obtaining their velocity. At the Mount Wilson solar tower, spectrograms of small areas enclosing a few granules were taken, and shifts measured. The main observational trouble arose from air movements. One plate proved to be much better than any other of the 300 taken, and this was used for measurement. There were about 80 granule spectra on this plate. The average of the velocities obtained was about 600 m.p.h., much lower than expected.

Australians have made determinations, using the fact that the Doppler effect of the random velocities will result in spectral "line broadening". Profile measurements gave expected results of about 5,000 m.p.h.

Both sets of measurements were good. The explanation seems to be that the high velocities are those of much smaller areas, too small to be resolved.

These velocities are definitely subsonic for the sun. Supergiant line profiles show supersonic velocities up to 40,000 m.p.h. The subsonic winds of the sun don't change the stellar picture much. The winds of the supergiants insert vast changes into the supergiant picture.

The estimated size of the wind elements in the sun is about 1,000 miles. The corona of the sun is at a temperature of 1,000,000°K. What keeps it at this temperature? One possibility is that sound waves due to atmospheric turbulence spread through the corona. The energy of the compression waves is dissipated in the corona as heat. Elements of 1,000 miles do not correspond to the right temperature; smaller elements give better results.

The thanks of the audience were tendered to the speaker by Dr. Helen Hogg.

IVAN ARON, *for Recorder.*

March 21, 1950.—A Member's Night was held in the McLennan Physics Laboratory. The Chairman was Mr. F. L. Troyer, Secretary. Two persons were elected to membership in the Society. These were:

Mr. James C. Jaimet, 115 Merner Ave., Kitchener, Ontario.

Mr. Francis P. McDonald, 1240 Davenport Road, Toronto 10.

Six persons were nominated for membership.

The topic for the night was, "An Advance Look at the Spring Sky". As a preliminary to the main topic, Mr. Ian Halliday, winner of the Royal Astronomical Society of Canada Gold Medal, gave a short talk on "The Seasons and Why They Occur".

The Secretary then gave an illustrated talk on the spring constellations, with slides showing their outlines, and views of some fascinating objects as seen in the telescope. This was extremely interesting and stimulated member participation to a new level.

Mr. C. A. Crook gave a "Handbook Talk", and Miss Northcott answered questions from the "Question Box".

April 4, 1950.—The meeting was held in McLennan Physics Laboratory, the Chairman being Mr. A. R. Clute, President.

Six candidates were elected to membership in the Society. These were as follows:

Miss Barbara Creeper, 66 Holly Street, Toronto 12.

Mr. Charles Faessler, 312 Wright Ave., Toronto 3.

Mrs. M. J. Faessler, 312 Wright Ave., Toronto 3.

Dr. A. Lloyd Morgan, 27 Douglas Crescent, Toronto 5.

Dr. Ethel Mott Morgan, 27 Douglas Crescent, Toronto 5.

Mr. George Matthewson, 81 Stuart Ave., Lansing, Ontario.

Two candidates were nominated for membership.

The President announced that F./L. Greenaway was unable to be present due to poor flying conditions. Dr. J. F. Heard filled in the vacancy as speaker. His subject was "The Earth as an Astronomical Body".

There are good reasons for astronomers to study the earth. It is the planet underfoot, and we can expect to learn more about it than the other planets. Then perhaps we can carry those facts over to the other planets and by comparison, learn how and when the 'planetary system' originated.

The size and shape of the earth are studied through astronomy and geography. The ancient Greek astronomers gave the world a heritage of ideas about the earth which was destined to last with little modification for nearly 2,000 years. One of these ideas was that the earth was essentially spherical. They calculated the circumference from astronomical effects differing with latitude. Nothing more was done until 1669, when Jean Picard measured the length of a degree of latitude in France. Shortly after this, scientists began to have differing opinions as to the earth's oblateness. In 1733 the French found that a degree of latitude was about 1.2 per cent. longer in Peru than in Lapland. The earth was oblate. In the century following, surveying was taken up with much vigour. It was found that results in mountainous regions were erratic due to deflection of the plumb line. Airy and Pratt found that corrections for this

were not simple, and put forward the principle of isostasy. This is equivalent to considering the mountain as a mass of granite floating low in a plastic mass of heavier rock so that the mountain roots comprise a deficiency as far as the plumb line deflection is concerned. Because of uncertainty in this correction, and because the continents are not geodetically connected, results are not perfect. The shape of the earth is at present being studied by means of gravity determinations which can be made under oceans in submarines. Perhaps the latest method of distance determinations involves timing the appearance of the shadow cone of a solar eclipse at different places, knowing the rate of travel of the shadow cone with accuracy from astronomical sources.

The structure of the earth is studied through astronomy, geophysics and seismology. Seismologists, by examining earthquake waves, detect a surface of discontinuity about half way to the centre of the earth. They believe that outside this there is a solid mantle, and that inside is a liquid core. An alloy, largely of iron, probably forms this core. It gives the correct average density for the earth. (Geochemists state that the mantle is largely of a rock called olivine). Iron is an abundant substance in nature and it does not mix well with the silicates. It is possible that in an earlier molten state of the earth, the liquid iron would have been gravitated to the centre. Iron might account for the earth's magnetism. Meteorites appear in two main classes, iron and stone. If they come from a disrupted planet, they indicate a core of iron for it. Ramsay throws serious doubts on the iron core hypothesis. He suggests that the core is of the same material as the mantle, but in a metallic phase. His theory suits planetary density variations in general, much better than the iron core hypothesis.

The water content of the earth is studied through astronomy, oceanography and meteorology. The earth is unique among the terrestrial planets in possessing reasonable quantities of water and oxygen. If the earth originally represented a sample of solar material, then as condensation took place, the lighter gases must have escaped except in so far as they were chemically combined to make heavy molecules. We have to account for the eventual presence of O_2 and H_2O in the atmosphere. It is supposed that H_2O and CO_2 evolved in large quantities from volcanoes. The O_2 probably was formed either from the CO_2 by the medium of plant life or by dissociation of the volcanic steam, the resulting light hydrogen escaping. In any event, it appears that oxygen and water go together in planetary atmospheres. The puzzle that remains is why the earth has these atmospheric constituents while other planets such as Venus do not have them.

April 18, 1950.—This was a Members' Night, the meeting being held in the McLennan Physics Laboratory. The Chairman was Mr. A. R. Clute, President.

Two applicants for membership, nominated at the meeting of April 4, were elected. These were:

Miss Edna A. Austin, Apt. 12, 148 Bloor St. W., Toronto.

Miss Mabel C. Jamieson, Streetsville, Ontario.

Upon motion by Mr. Troyer and approval of the meeting, By-law No. 1 was suspended for this occasion and four new applicants were nominated and elected to membership. These were as follows:

Mr. John Alan Bacon, 309 Briar Hill Ave., Toronto 12.
Mr. Robert F. Hurst, 5 Withrow Ave., Toronto 6.
Mr. John A. Montague, 41 Sussex Ave., Toronto 5.
Mr. John Penner, B.A., Pickering College, Newmarket, Ontario.

Dr. J. F. Heard reviewed two books before the meeting. His review of one of these, "The Conquest of Space", by Chesley Bonestell and Willey Ley, is to be found in the Society's JOURNAL, vol. 43, no. 6, page 241. The other book was "A Concise History of Astronomy" by Peter Doig, (Chapman and Hall). The book is well written, giving a condensed history up to the beginning of the 19th century, and a fuller description from then on. The author makes good use of tables.

Mr. C. A. Crook discussed phenomena occuring in May.

Mr. R. L. Baglow reviewed Velikovsky's "Worlds in Collision". His review is to be found in the Society's JOURNAL, vol. 44, no. 3, page 118. A warm discussion followed this presentation.

Miss Northcott answered questions from the question box.

October 18, 1950.—This meeting was held at the David Dunlap Observatory, Richmond Hill, on the invitation of the Director, Dr. F. S. Hogg. The chairman was Mr. A. R. Clute, President.

Sixteen people were nominated for membership in the Society. There was one transfer from the Winnipeg Centre.

The formal meeting was then adjourned.

Members were shown around the Observatory and viewed the 74-inch telescope. Small telescopes were set up, with which to view the moon and Jupiter (through some rather annoying clouds).

Some books and periodicals were on display in the main building, and Dr. Hogg demonstrated the Observatory's projection comparator.

October 31, 1950.—The meeting was held in McLennan Physics Laboratory, the Chairman being Mr. A. R. Clute, President.

The following candidates, nominated October 17th, were elected to membership for 1950:

Mr. Hugh J. Bell, 324 Russell Hill Road, Toronto 12
Mr. George C. Black, 78 Eldon Ave., Toronto 13
Miss Phyllis Coffey, 324 Russell Hill Road, Toronto 12
Miss Chica Jones, 34 Whitehall Road, Toronto 5
Mr. Norman Kotani, 1428 Gerrard St. E., Toronto 8
Mr. G. H. Turner, Little Current, Ontario

The following candidates, nominated October 17th, were elected to membership for 1951:

Mr. Morris A. Altman, 227 Vaughan Road, Toronto 10
Mrs. Ruth Arntz, 308 Carlton St., Toronto 2
Mr. J. F. Campbell, 93 Castle Knock Road, Toronto 12
Mr. Lionel H. Clark, 328 Hillsdale Ave. E., Toronto 12
Mr. Grant A. Cooper, 44 Sunnybrae Cres., Toronto 9
Mr. George A. Duthie, 12A Glen Avon Road, Toronto 3

Mr. Kurt A. Frenkel, 8 Yarmouth Gdns., Toronto 4
Miss Nancy Minchin, Whitefish Falls, Ontario
Miss Joan G. Sloman, 566 Sherbourne St., Toronto 5
Mr. Harry Worsick, 1870 Davenport Road, Toronto 9

In addition, Mr. Kenneth C. McCulloch, 119 Orchard View Blvd., Toronto 12, has applied for admission to Toronto Centre membership by transfer from Winnipeg Centre.

Five candidates were nominated for membership in the Society.

The President introduced the speaker, Mr. John Galt, B.A., now a graduate student at the University of Toronto. Mr. Galt has been at Resolute Bay in the Canadian Arctic for a year, doing magnetic work for the Dominion Observatory. Mr. Galt's talk was entitled, "Where the Dip Needle Stands on End".

Mr. Galt described the earth's magnetic field, and explained the use of the dip-circle and other instruments in finding the horizontal and vertical components of the earth's field at any point. Magnetic poles can be located in this way. The north magnetic pole is not stationary, but varies by 50 or 100 miles on a disturbed day. The Dominion Observatory has established stations in the Arctic to study any variation in and find any possible orbit for this elusive pole. It was to one of these stations that the speaker was assigned.

Mr. Galt showed lovely coloured slides of his trip. There is snow every month of the year at the station, and in the winter the temperature often goes down to the minus forties.

The speaker's talk was warmly received by the Centre. Mr. Galt had explained the technical side of the subject very clearly and concisely, and had realistically portrayed the Arctic life.

W. R. Hossack, *Recorder.*

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